



Electrical Quality Assurance for the IT String (WP7/TE-MPE)

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Outline:

- Documentation and procedures
- Equipment, software
- Feedback of the experience of ELQA in the individual magnets, S.C. Link and other circuit components
- Status of the collaboration

ELQA in the IT String - objective

- Validate the superconducting circuits for cool-down and powering
- Acquire working experience on HL-LHC circuits
- Acquire reference values for HL-LHC circuits and components
- Validate ELQA test procedures, ELQA test equipment and software
- Ensure that the qualification is as tight as possible and that there is no negative impact on HL circuits
- The ELQA in the IT String should be as similar to the final ELQA in the tunnel as possible

HL-LHC ELQA Documentation

- For each magnet (and associated cold/warm powering component) an EDC document has been created:
 - Magnets
 - Superconducting Link System
 - D1-DFX, D2-DFM Interconnection modules and Superconducting busbars in HL-LHC Line N1 and Line N2
 - Circuit components operating at room temperature
- Necessary voltage withstand and test levels at various conditions and at various manufacturing stages are defined
 - ✓ Documents can be found on EDMS here: <https://edms.cern.ch/project/CERN-0000229487>
- ELQA needs to perform a set of specific tests for each asset at different conditions, called a qualification set
 - ✓ The test program is described in: <https://edms.cern.ch/document/2746933>
- Each of these qualification sets require their own specific test procedure.
 - ✓ Documents can be found on EDMS here: <https://edms.cern.ch/project/CERN-0000229486>

Qualification Sets Include:

- SLC
- MIC (C,W,D)
- ITIV
- ITIC
- IT-PAQ
- TP4 (A,B,C,D,E)

EDMS NO. 2824470 | REV. 0.2 | VALIDITY DRAFT
 REFERENCE : LHC-D-ES-0015

ENGINEERING SPECIFICATION

MAGNET CIRCUIT FORUM

ELECTRICAL DESIGN CRITERIA FOR THE HL-LHC CIRCUIT OPERATING AT ROOM TEMPERATURE

EDMS NO. 1963398 | REV. 6.0 | VALIDITY VALID
 REFERENCE : LHC-MQXF-ES-0001
 US HL-LHC-AUP#: US-HiLumi-doc-879

ENGINEERING SPECIFICATION

ELECTRICAL DESIGN CRITERIA FOR THE HL-LHC INNER TRIPLET MAGNETS

Abstract
 This document describes the strategy to be applied in order to define the voltage withstand levels for the MQXF superconducting magnets manufactured both under the US HL-LHC Accelerator Upgrade Project and CERN. The values presented here will be the reference to be used during the reception tests, further qualifications, installation and commissioning as systems in the LHC tunnel.

EDMS NO. 0000000 | REV. 0.0 | VALIDITY DRAFT
 REFERENCE : LHC-EQCOD-XP-XXXX

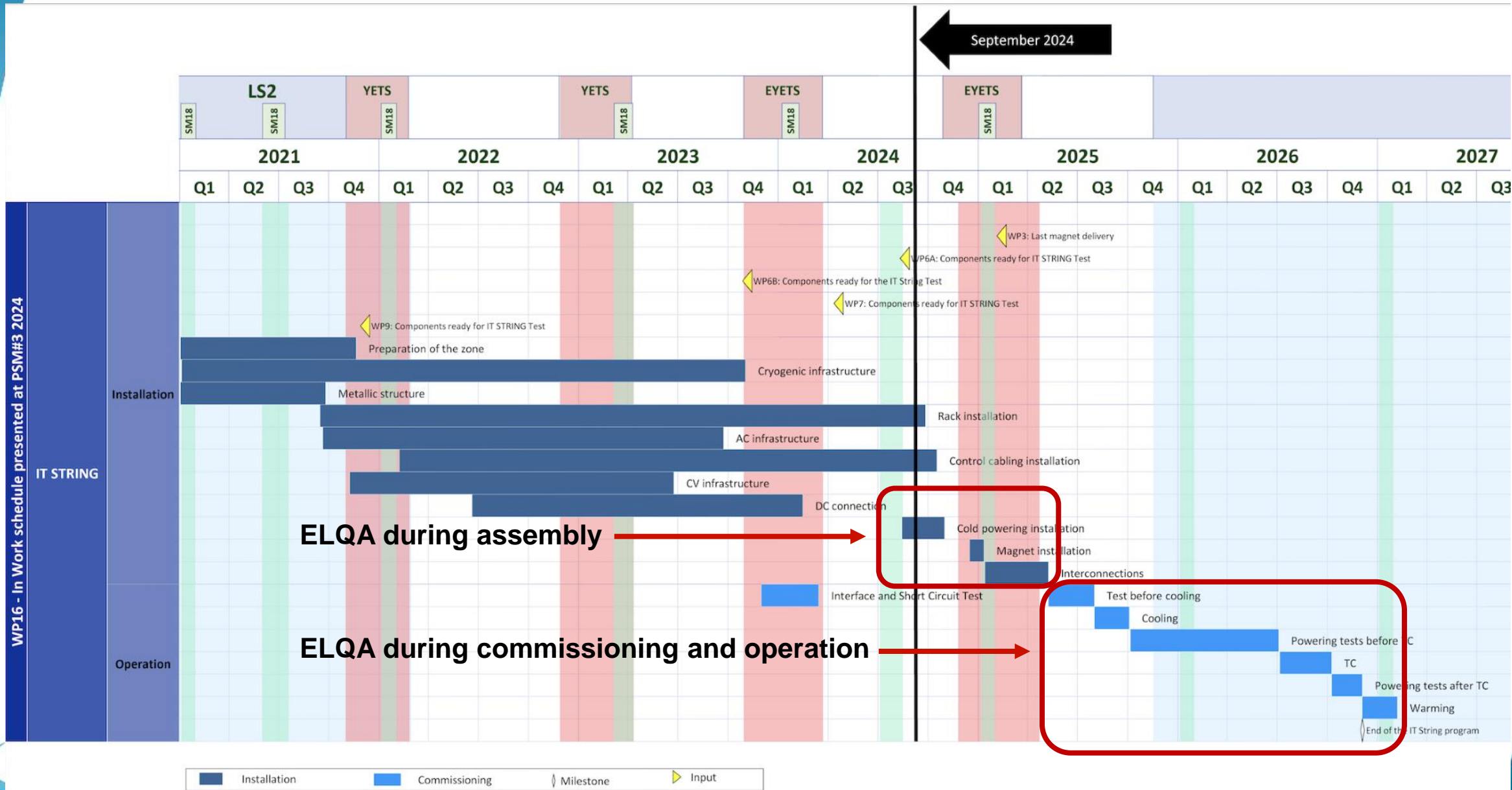
PROCEDURE

SUPERCONDUCTING LINK CHECK (SLC) PROCEDURE ON THE F2 BENCH IN SM-18

describes the test procedure to be applied during ELQA Superconducting Link Check (SLC) on the



IT String planning



ELQA during the IT String assembly

	SLC	MIC-W	IT-PAQ	ITIV	ITIC
HVQ	✓	✓	✓	✓	✓
TFM	✓	✓	✓	✓	
IRC	✓	✓	✓	✓	
ICC	✓	✓	✓	✓	
TDR	✓	✓	✓		✓
COC	✓			✓	✓
QHR		✓			
DVC			✓		
TSQ	✓		✓		

HVQ – High Voltage Qualification
 TFM – Transfer Function Measurement
 IRC – Instrumentation Resistance Check
 ICC – Instrumentation Configuration Check
 TDR – Time Domain Reflectometry
 COC – Continuity of Conductor check
 QHR – Quench Heater Resistance measurement
 DVC – Diode opening Voltage Check
 TSQ – Temperature Sensor Qualification

Done already on several IT String assemblies!

SLC – Superconducting Link Check
 MIC-W – Magnet Instrumentation Check
 IT-PAQ – Inner Triplet Partial Assembly Qualification
 ITIV – Inner Triplet Interconnection Verification
 ITIC – Inner Triplet Instrumentation Check

ELQA during the IT String commissioning

	TP4-A	MIC-W	TP4-B	TP4-C	TP4-D +MIC-D	MIC-C	TP4-E
	At warm	At warm	After flushing	During cool-down/ warm-up	At 80 K	At cold	At cold
HVQ		✓	✓	✓	optional	✓	✓
TFM	✓	✓			optional	✓	✓
IRC	✓	✓			optional	✓	✓
ICC	✓	✓			optional	✓	✓
TDR		✓			optional	✓	
QHR		✓			optional	✓	
DVC		✓				✓	
TSQ	✓						✓

TP4-A – Test Procedure 4 type A

MIC-W – Magnet Instrumentation Check at warm

TP4-B – Test Procedure 4 type B

TP4-C – Test Procedure 4 type C

TP4-D – Test Procedure 4 type D

MIC-D – Magnet Instrumentation Check at 80 K

MIC-C – Magnet Instrumentation Check at cold

TP4-E – Test Procedure 4 type E

HVQ – High Voltage Qualification

TFM – Transfer Function Measurement

IRC – Instrumentation Resistance Check

ICC – Instrumentation Configuration Check

TDR – Time Domain Reflectometry

QHR – Quench Heater Resistance measurement

DVC – Diode opening Voltage Check

TSQ – Temperature Sensor Qualification

ELQA during the IT String commissioning and operation

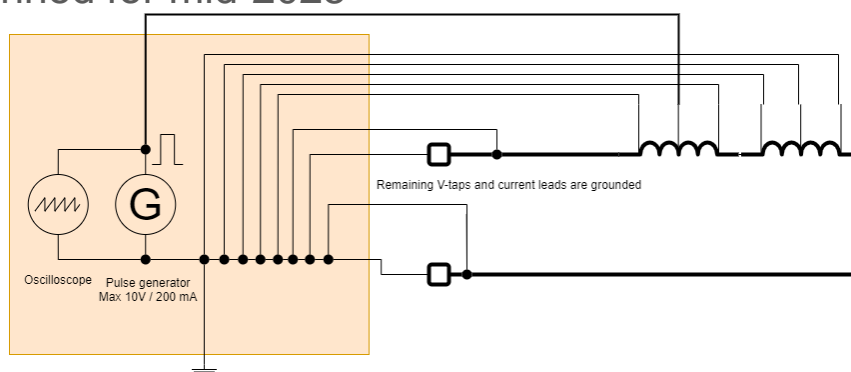
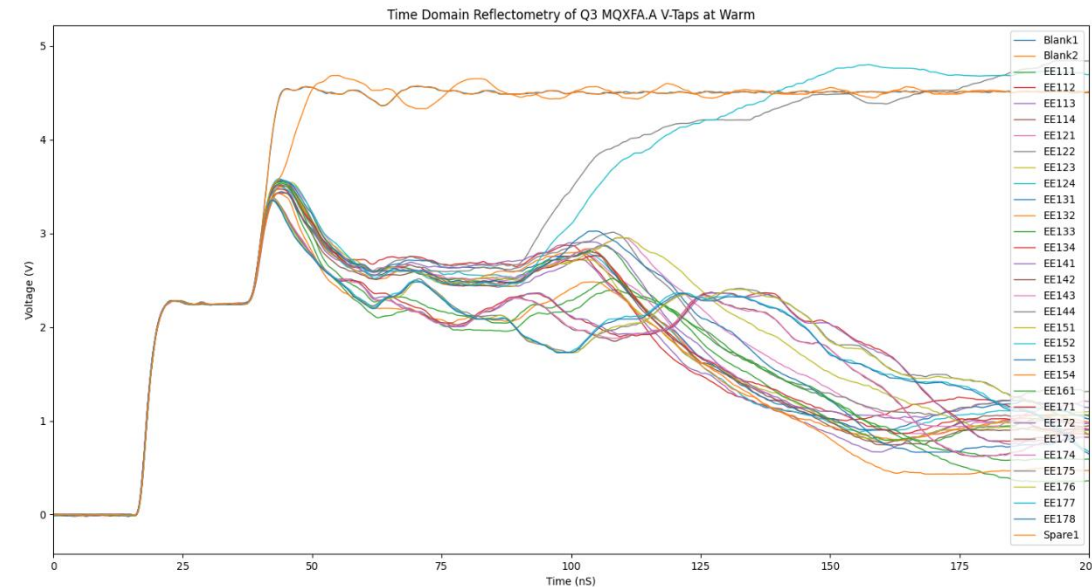
Qualification set	At warm	At warm after flushing	Cool-down 300 K to 80 K	At 80 K	Cool-down 80 K to 1.9 (4.5) K	At cold	At cold after powering	Warm-up	At warm	Cool-down	At cold	At cold after powering	Warm-up	At 80 K	Warm-up 80 K to 300 K	At warm
TP4-A	>								>							>
MIC-W		>							>							>
TP4-B		>							>							>
TP4-C			>		>			>		>			>		>	
TP4-D				>										>		
MIC-D				>										>		
MIC-C						>	>				>	>				
TP4-E						>	>				>	>				

Status of test systems

- Automated tests (test applications, database, measurement sequences and validations) implemented and ready for
 - All IT String magnets
 - S.C. link conductors
 - Instrumentation cables
- Adaptor cables ready to match all connectors in the IT String
- First magnets and the S.C. link tested on the test benches
 - @warm and @cold
 - More than 20500 measurements and even more validations so far!
- Interconnection verification needs to be finalised

Development of new tools (TDR)

- Time Domain Reflectometry (TDR) is a very useful technique for probing cable impedance changes along the cable, in particular to localise open circuits or short circuits
 - Reference signal of a healthy circuit is needed
- For HL-LHC and IT String ELQA is going to systematically acquire these reference signals in multiple configurations on most of instrumentation wires
- A single channel version is operational already
- A dedicated multichannel device is being developed (in collaboration with IFJ PAN)
 - Prototype PCB is being launched for production
 - Working prototype expected before the end of the year (to be used in the IT String)
 - Final two units planned for mid-2025



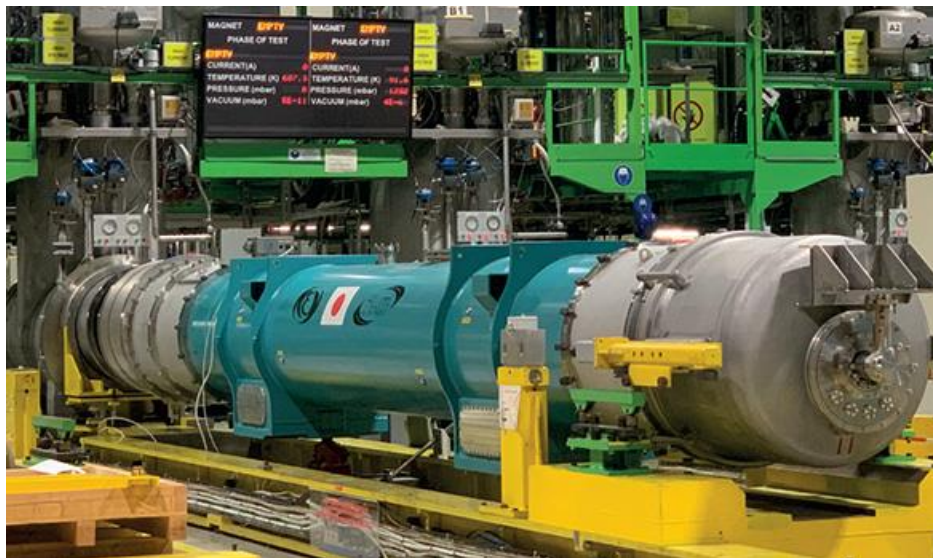
Manpower for the ELQA in the IT String

- Particular attention to be put on verification of ELQA methods, procedures, hardware and software
- Personnel will be provided by TE-MPE-PE
- Support of ELQA experts from IFJ PAN in key IT String time slots
 - Dedicated Addendum to existing Collaboration Agreement is in place
 - Preliminary dates:
 - 3 weeks in Nov./Dec. 2024
 - 4 weeks in Jan./Feb. 2025
 - 7 weeks in Jun./Jul. 2025



Examples of Assets Tested So Far

D1 (HCQBXF_S007-CR000001)



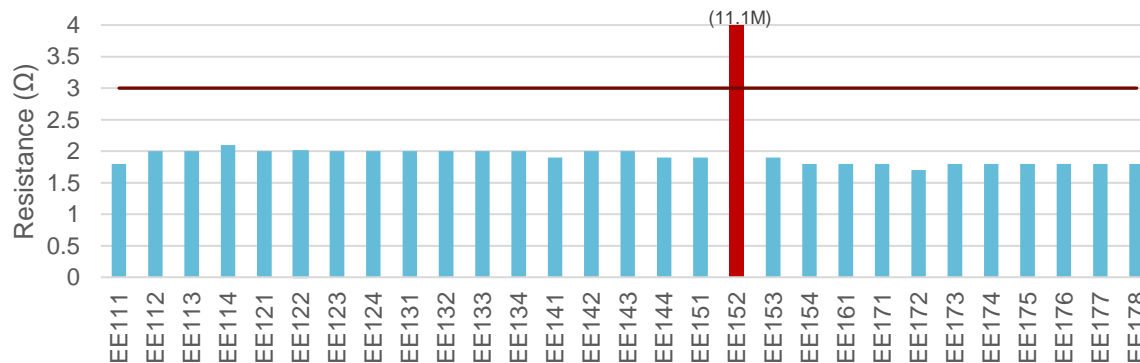
SCL (HCDSHX_002-CR000001)



Q2B, Q2A, Q2B (HCQAXF_SB014-CR000001, HCQAXF_SA008-CR000001, HCQAXF_SB014-CR000002)

Experience with ELQA on HL magnets and S.C. link

- So far tested 6 magnets and one complete S.C. link assembly on test benches in SM18 (typically twice at warm and once at cold)
 - Smooth test execution
 - Minor issues related to a couple of lost V-taps identified
 - Reference data for all test types acquired
 - Fine-tuned the software, hardware, test content, validations and detection thresholds
- Performed fault localisation on a couple of magnets
 - Earth fault on a busbar in Q2b magnet
 - Insulation failure on a quench heater



Experience with ELQA on IT String components

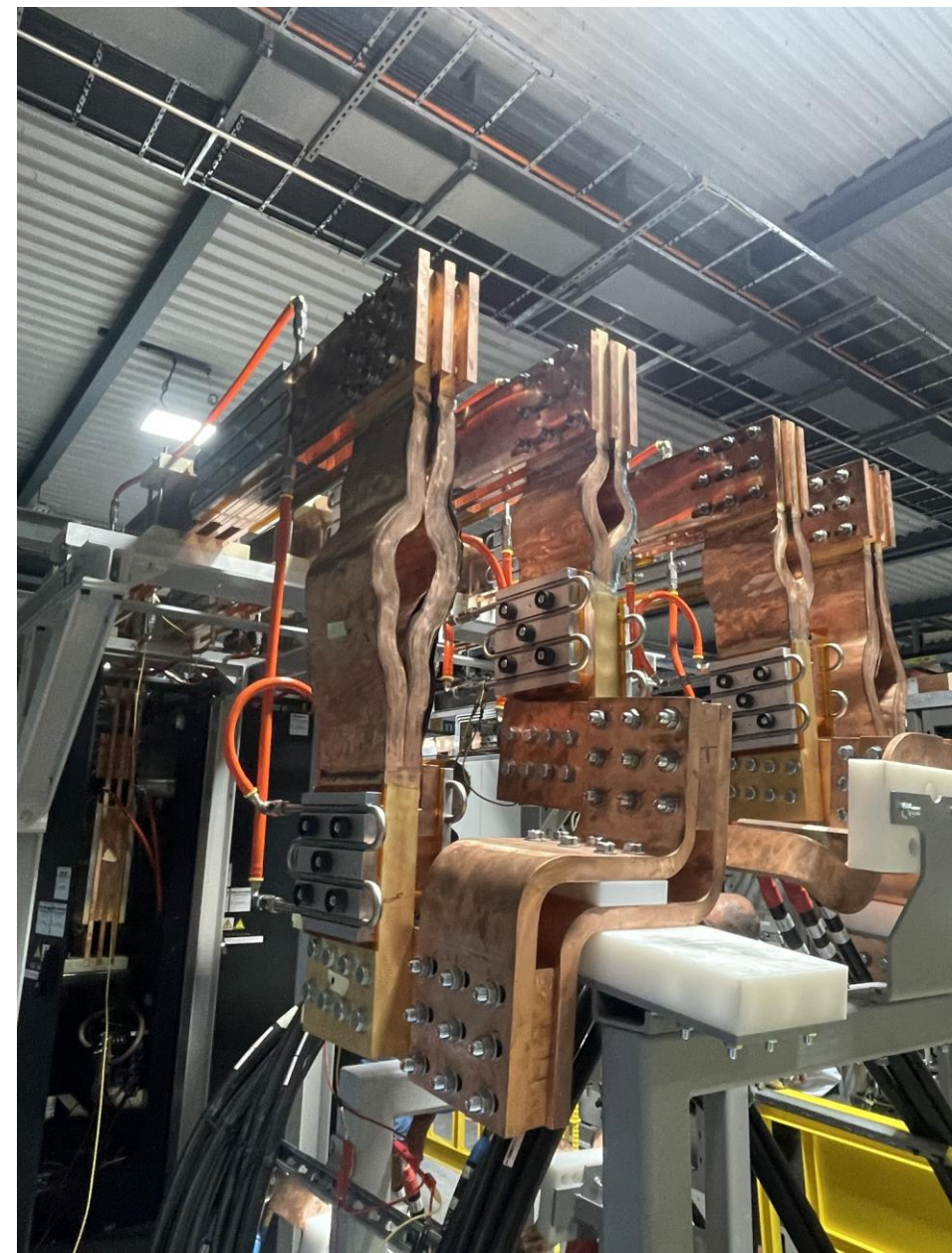
- Several components tested:
 - Warm diode assembly
 - CDBs
 - Warm water-cooled busbars
 - Instrumentation cable samples
 - QDS patch panel prototype

WARNING!

Warm water cooled busbars

- Insulation was found insufficient wrt the EDC requirement
- Dedicated tests were repeated such that the insulation of each water-cooled plate could be assessed
- The insulation was found to breakdown **in 5 out of 16 plates**
- Corrective and mitigation actions are undertaken

- Detailed report: <https://edms.cern.ch/document/3092105/>
- Presentation: <https://indico.cern.ch/event/1448991/>



Instrumentation cable samples

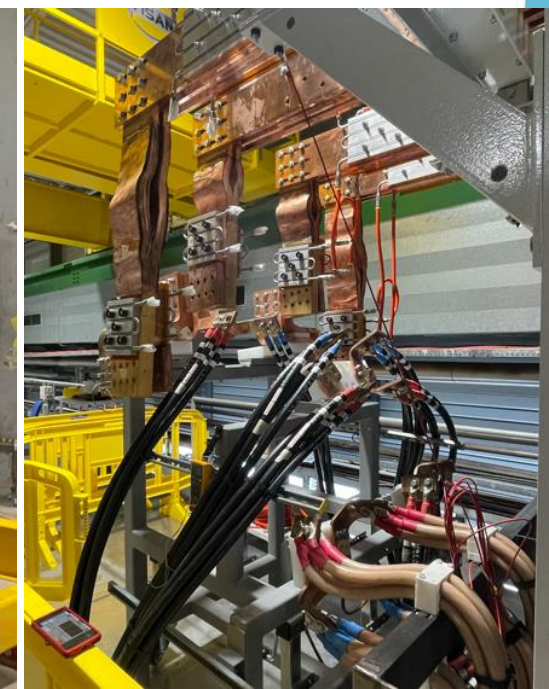
- 22 cables
- 518 wires to test (HV tested at least 4 times each)
- Insulation successfully tested at 1 kV, 2.7 kV and 3 kV on all wires
- Selected wires successfully tested up to 12 kV
- **Component selection is sufficient for IT String operation, no degradation expected during the final 2.7 kV test in the IT String**
- **Continuity errors in 9 out of 22 cables**
- Discussions with EN-EL took place and resulted in a complete requalification of the IT String cables
- It is planned that ELQA will retest the IT String instrumentation cables
- Detailed report: <https://edms.cern.ch/document/3121209>
- Presentation: <https://indico.cern.ch/event/1448991/>



Upcoming Priorities

Following assets will soon be tested:

- Corrector Package assembly
- Q3 at warm
- Instrumentation cables in the IT String
- S.C. link in the IT String
- Re-validation of warm water-cooled busbars
- Tests of IT String magnets after installation in the IT String



Summary

- ELQA is ready to test IT String components and circuits as soon as they become available
- Documentation and most of the required procedures for HL-LHC are available, to be finalised with the help of experience gained in the IT String
- Software, hardware and cables are ready
- Development of the dedicated multichannel TDR will soon be at the fully functional prototype stage
- Several HL-LHC and IT String assets have been tested
 - Experience with the new types of equipment was acquired and translates into optimisations of the ELQA HL-LHC systems
 - Reference data was acquired and will serve for future tests
 - Several early warnings were identified and help improve HL-LHC components
- Additional support of ELQA experts from IFJ PAN is planned in key time slots

